MRL-R-716 LEVEL AR-000-895

AD A073411

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-716

500 LB CONCRETE PRACTICE BOMB : A FEASIBILITY ASSESSMENT

Frederick W. Shier

Approved for Public Release

JUNE, 1978

DEPARTMENT OF DEFENCE

MATERIALS RESEARCH LABORATORIES

REPORT

MRL-R-716

500 LB CONCRETE PRACTICE BOMB : A FEASIBILITY ASSESSMENT

Frederick W. Shier

ABSTRACT

Preliminary results show that reinforced concrete is a promising material for producing practice versions of the 500 lb MK82 bomb. To duplicate the mass and moment of inertia of the live store the concrete is required to have a density range of 2.5 to 3.2 g cm^{-3} depending on the amount and distribution of steel in the design chosen. The higher concrete densities can be achieved by using haematite as aggregate.

Substantial savings in the unit cost of practice bombs are indicated particularly when the quantity of steel in a design is reduced.

Compliance with the flight, arrest and catapult conditions of MIL-A-8591E have been shown by computation. Prototype building and testing has still to be performed before full compliance with MIL-A-8591E can be assured.

Approved for Public Release

POSTAL ADDRESS: Chief Superintendent, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

Security classification of this page: UNCLASSIFIED

1. DOCUMENT NUMBERS:
   a. AR Number: AR-000-895
   b. Series & Number: REPORT MRL-R-716
   c. Report Number: MRL-R-716

2. SECURITY CLASSIFICATION:
   a. Complete document: UNCLASSIFIED
   b. Title in isolation: UNCLASSIFIED
   c. Abstract in isolation: UNCLASSIFIED

3. TITLE:

500 LB CONCRETE PRACTICE BOMB : A FEASIBILITY ASSESSMENT

4. PERSONAL AUTHOR(S):

SHIER, Frederick W.

5. DOCUMENT DATE: JUNE, 1978

6. TYPE OF REPORT & PERIOD COVERED:

7. CORPORATE AUTHOR(S):

Materials Research Laboratories

8. REFERENCE NUMBERS:
   a. Task: AIR 94/014
   b. Sponsoring Agency: RAAF 1CAMD

9. COST CODE: 231320

10. IMPRINT (Publishing establishment)

Materials Research Laboratories,
P.O. Box 50, Ascot Vale, Vic.3032

JUNE, 1978

11. COMPUTER PROGRAMME(S):
(Title(s) and language(s)):

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release

12-0. OVERSEAS: N.O. [ ] P.R. [1] A [ ] B [ ] C [ ] D [ ] E [ ]

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

No Limitation

14. DESCRIPTORS:

Practice bombs; Concrete products; Heavyweight concretes.

15. COSATI CODES: 1902

16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

Preliminary results show that reinforced concrete is a promising material for producing practice versions of the 500 lb MK82 bomb. To duplicate the mass and moment of inertia of the live store the concrete is required to have a density range of 2.5 to 3.2 g cm^{-3} depending on the amount and distribution of steel in the design chosen. The higher concrete densities can be achieved by using haematite as aggregate.

Substantial savings in the unit cost of practice bombs are indicated particularly when the quantity of steel in a design is reduced.

Compliance with the flight, arrest and catapult conditions of MIL-A-8591E have been shown by computation. Prototype building and testing has still to be performed before full compliance with MIL-A-8591E can be assured.

C O N T E N T S

500 LB CONCRETE PRACTICE BOMB : A FEASIBILITY ASSESSMENT

1. INTRODUCTION

This report sets out the results of an investigation into the feasibility of designing a 500 lb MK82 type practice bomb in reinforced concrete. The attractions of this concept include lower unit cost, smaller capital outlay on production equipment, the use of readily available Australian materials and simplified quality assurance provisions.

The scope of this study has been to generate the necessary design data, to explore the properties of the bomb shape, to examine the properties of the proposed construction materials and to assess design loads. A preliminary design has been developed for the purpose of demonstrating the salient features of a concrete bomb and to highlight the direction to be taken in optimising a design. Whereas the bomb illustrated in this report uses conventional portland cement concrete, a more economical design would use less steel in the bomb and be constructed of higher density concrete. No prototypes have yet been cast.

2. DESIGN FEATURES OF A CONCRETE BOMB

The bomb is basically a steel reinforced concrete beam and differs markedly from the existing structure in that it does not utilise a steel outer casing. Figure 2 shows the basic configuration of the bomb. The functional elements of the structure are as follows.

A ten inch nominal bore schedule twenty tube acts to transmit air carriage loads into the bomb via the conventional suspensional lug insert and multiple lug insert. Two mild steel braces are used to provide additional support for the rear suspension lug insert. Conventional fuzing fitments are used.

Longitudinal tension loads and tension bending is borne by the reinforcement rods; longitudinal compression loads and bending compression is sustained by the concrete. The reinforcement rods are welded to the mild steel inserts in the nose and tail of the bomb. These inserts also provide for the attachment of the fuze cavity liners, fuzes, closure plug and tail assemblies.

Shear forces may be considered as being sustained by both the concrete and the steel reinforcement although reinforced concrete practice is to avoid loading the concrete in shear. It may also be noted that the circular cross section of the structure does not lend itself to the efficient use of the concrete when using the traditional "concrete in compression only" design techniques. Greater efficiency of design would be obtained if the concrete were permitted to accept some tensile loading; such an approach would require closer attention to the design of the reinforcement to control cracking.

The density of the concrete used in the bomb depends on the quantity and distribution of the steel used in a given design. If a design uses a small amount of steel (this implies an economical design) then the required mass and moment of inertia of the bomb must be provided by the concrete. High density concrete that can achieve mass and moment of inertia values in a hypothetical steel-less bomb has been achieved by a mix consisting of Portland cement, sand and haematite pellets, the latter being used in lieu of the conventional coarse aggregates. The design illustrated in this report contains sufficient steel to obviate the use of high density concrete.

Conduits or cavities may be incorporated in the bomb provided that due consideration is given to the effect that such modifications could have on the structural integrity of the bomb.

3. BOMB PROPERTIES

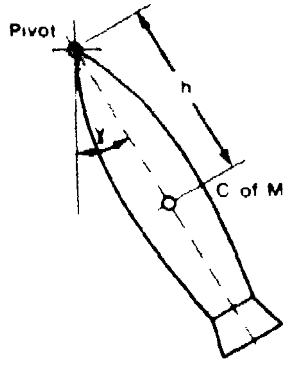
3.1 Aerodynamic Properties

The shape of the concrete bomb is identical with that of the standard 500 lb MK82 bomb. Aerodynamic data from one eighth scale wind tunnel tests of a slick tailed bomb has been used. These tests were conducted at Defence Research Centre (formerly Weapons Research Establishment) Salisbury, South Australia.

3.2 Dynamic or Inertial Properties

The mass and distribution-of-mass data in the existing bomb and in the proposed concrete bomb have been computed, and where practicable the computed figures were verified by experiment.

Centres of mass were determined by finding points of balance and moments of inertia were found by measuring the period of oscillation of the bombs and using the relationship between period and moment of inertia of a compound pendulum as follows.



$$T = 2\pi\sqrt{\frac{k^2}{gh}}$$

equation holds for $\gamma \simeq \sin\gamma$ i.e. $\gamma \leqslant 4°$

k = radius of gyration which is related to moment of inertia (I) by $I = Mk^2$ where M is the mass.

h = distance between pivot and centre of mass.

T = period of oscillation.

Figure 1 - Determination of Moment of Inertia

The moment of inertia about the bomb nose was used to calculate the moment of inertia about the centre of mass by means of the parallel axis theorem. The results of the determinations of inertial properties together with associated data extracted from ARDU Test Schedule 1602 are given in Table 1.

4. HIGH DENSITY CONCRETE

The use of an appropriate high density concrete mix will be necessary to achieve the required mass and moment of inertia if the steel content of the bomb is to be minimised. A limited study has been made of a high density concrete prepared by using :

Fresh portland cement,

Fine aggregate consisting of clean sharp sand of bulk density 1.53 g cm^{-3} (dry),

Coarse aggregate of haematite pellets manufactured (via the Lurgi process) as blast furnace feedstock.

The pellets used in the test sample were approximately spherical and had a bulk density of 2.08 g cm^{-3} (Haematite density is 5.24 g cm^{-3}). Although this is not the ideal shape for a coarse aggregate, satisfactory concrete compression strengths were obtained.

It is considered that haematite is a suitable high density material for both fine and coarse aggregates. Haematite is chemically inert, compatible with portland cement and available in tonnage quantities from sources throughout Australia.

The mix design was by the displacement method (2). The maximum density could not be achieved as the spherical haematite balls "snowballed" in the mixer, i.e. the sand/cement/water mixture coated the pellets to form enlarged

spheres and the pellets did not spread throughout the cement/water/sand mix. The maximum density achieved has been 3.2 g cm^{-3}.

The mix proportions by weight were :

Haematite pellets	60.8%
Dry sharp sand	24.9%
Cement	8.0%
Water	6.3%

Replacement of the sand with crushed haematite or other high density aggregate would yield a higher density mix.

Three 300 mm long x 150 mm diameter test specimens prepared using the mix proportions tabulated gave the following mean values when tested under the standard test conditions.

Compressive strength at failure	37.9 MPa
Modulus of elasticity	38.0 GPa

The test specimens showed the conventional form of concrete failure in such test cylinders. The principal mechanism of failure appeared to be shearing of the haematite/cement paste bond with only the occasional haematite pellet being fractured.

5. DISCUSSION OF DESIGN COMPUTATIONS

The criterion used to assess feasibility is compliance with MIL-A-8591E. Work has concentrated on assessing the inertial and aerodynamic loadings on the bomb due to flight, catapult and arrest. Specification aspects such as aeroelasticity, impact testing and environmental testing have yet to be considered.

Because of the number of possible different critical design conditions an estimated worst case has been selected. A worst-case inertial loading has been added to a worst-case aerodynamic loading. This gives a conservative estimate of loading on the bomb.

Computations for assessing stress in the bomb were considered in three phases :

(a) Assessment of aerodynamic forces.

(b) Inertial-loading assessment in the form of shear force and bending moments due to unit rotational acceleration and unit lateral acceleration.

(c) Determination of the actual shear force and bending moments by suitably scaling the results of (b).

The amount of reinforcement in the bomb was then determined.

(a) Assessment of Aerodynamic Forces

The aerodynamic forces were calculated using values of angle of attack (α) and sideslip (β) derived from Figure 14 of MIL-A-8591E. These values were transformed into a system of coordinates corresponding to those used for wind-tunnel data. The results are set out in Appendix 6.

(b) Stresses due to Rotational and Lateral Accelerations

Load, shear-force and bending-moment diagrams were constructed for unit rotational acceleration and for unit lateral acceleration. These diagrams are set out in Appendix 7.

(c) Actual Shear Forces and Bending Moments, and Reinforced Concrete Computations

The unit-load, shear-force and bending-moment diagrams were suitably amplified by the derived values of rotational and translational accelerations. The turning moment on the bomb due to aerodynamic forces was transformed to a rotational acceleration by dividing the turning moment by the moment of inertia with the assumption that the pressure distribution is equivalent to the inertial moment distribution. This assumption tends to underestimate the effects of aerodynamic loading. The maximum bending moment and shear force were obtained by linear superposition.

The assessment of bending stresses in the structure required the analysis of stress distribution in the reinforced-concrete composite beam. The stress distribution was derived in two steps :

(i) Determination of the cross-sectional area of steel required to carry the tensile forces (neglecting the strength of the 10" N.B. pipe).

(ii) Determination of the maximum stress in the concrete, neglecting the effect of the steel.

The results of the computations showed that the stresses in the concrete are small. A more sophisticated design approach of allowing the concrete to carry limited tensile loads would lead to greater design economy.

The effects of stress concentration due to the abrupt change in stiffness at the edge of the 10" N.B. steel tube have not been considered in the design computations.

6. COST PROFILE

Table 2 shows the cost contribution of the parts, material and labour to the estimated overall cost of the bomb illustrated in Figure 2. This estimate indicates that the concrete constitutes only a small fraction of the total cost of the store whereas the steel will contribute significantly to the total cost. Therefore the optimal design solution is in the direction of reducing the steel content of the bomb.

The estimated total cost of $200 for the design shown in Figure 1 compares favourably with the current cost for the existing practice bomb of approximately $500.

7. CONCLUSIONS

The study has indicated that it should be feasible to design and produce reinforced concrete practice bombs acceptable for external air carriage. Several design options appear to be available. These range from high steel content in association with normal concrete to low steel content with high-density concrete.

The direction of further work would include the following aspects :

(1) More sophisticated and detailed design analysis.

(2) Investigations into denser concrete mixes and their properties.

(3) Assessment of explosively induced fragmentation properties of concrete.

(4) Environmental and other qualification testing of proposed concrete bombs to the full requirements of MIL-A-8591E.

(5) The possibility of brittle fracture in the steel components of the bomb due to low-temperature service. The correct selection of steel and the use of suitable welding techniques normally overcome such problems.

8. REFERENCES

1. Military Specification General Design Criteria for Airborne Stores, Associated Suspension Lugs and Aircraft-Store Interface (Carriage Phase); MIL-A-8591E.

2. Taylor, W.H. (1969). Concrete Technology and Practice, 3rd ed. Angus and Robertson.

3. Timoshenko, S. and Young, D.H. (1962). Elements of Strength of Materials, 4th ed. Van Nostrand.

4. Computer Printout Data of Wind Tunnel Tests on Slick Tail 500 lb MK82 Bomb. Source W.R.E. Salisbury, South Australia.

5. AS Code 1480 - 1974.

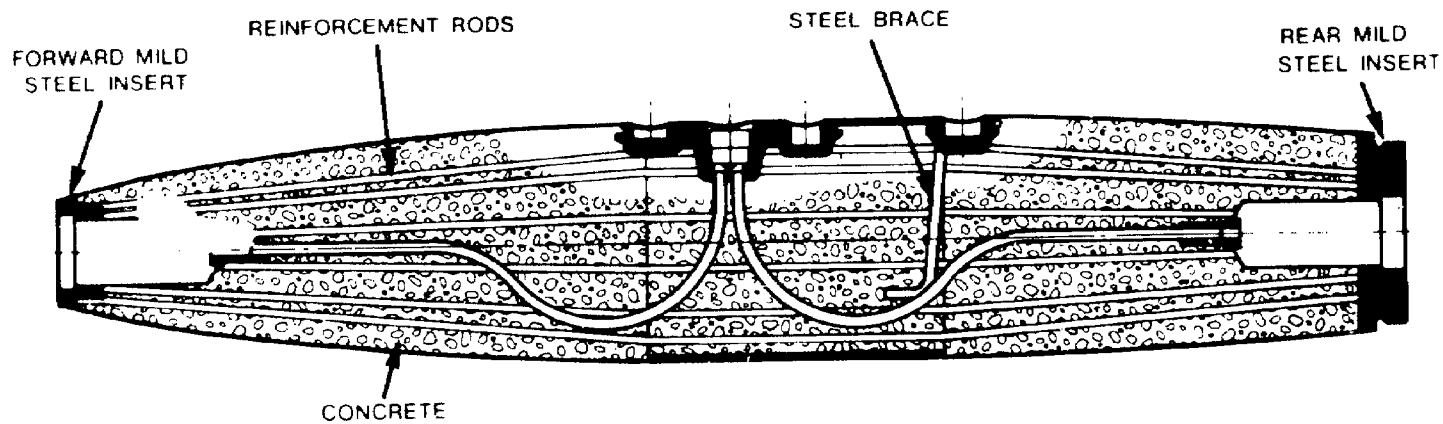


FIG. 2 - Proposed Steel Reinforced Concrete Bomb.

T A B L E 1

INERTIAL PROPERTIES OF 500 LB BOMB

(1) Hardware Configuration	(2) Mass (kg)	(3) Centre of Mass (a) (m)	(4) Radius of Gyration about Nose (m)	(5) Radius of Gyr'n about C of M (m)	(6) Moment of Inertia about C of M (kg m^2)
(1) Standard forged bomb case.	125	.73	.88	.44	24.14
(2) Inert filled bomb without closure plug	219	.80	.90	.41	36.81
(3) Inert filled bomb with closure plug	222	.80	.91	.43	41.05
(4) Inert filled bomb with closure plug and slick tail	232	.85	.97	.48	53.45
(5) Inert filled bomb with plug and retarder tail	252	.92	1.06	.515	67.01
(6) Filling of SG = 1.67 Calculated values of filling only (see Appendix 1)	97	.91	0.98	0.36	12.84
(7) Estimate of properties of concrete only bomb (SG = 3.2) (see Appendix 3)	227	.81	.90	.40	35.92
(8) Estimate of properties of steel components in concrete bomb	18.7	-	-	-	6.4
(9) MK82 bomb, filled HES and fitted with slick tail - ARDU Test Schedule 1602	230	.86	-	-	51.6

Note: (a) measured from machined face on bomb nose.

TABLE 2

COST STRUCTURE OF PROPOSED CONCRETE PRACTICE BOMB, 500 LB MK82 SHOWN IN FIGURE 1

No.	Description	Req'd.	Estimated Unit Cost $	Total Cost $	% of Cost
1	For'd mild steel insert	1	15	15	11
2	Aft mild steel insert	1	10	10	7
3	Multiple insert	1	6	6	4
4	Suspension insert	1	4	4	3
5	Fuze cavity liner	2	5	10	7
6	Conduit	2	2	4	3
7	Reinforcement rods			3	2
8	Concrete	0.07 m^3	40/m^3	3	2
9	Mild steel skirt - 10" N.B. Schedule 20	.36 m	40.52/m	15	11
10	Tooling: Bomb	-	-	10	7
11	Labour: Welding, mixing concrete, casting etc.	6 mh	10/mh	60	43
12	Subtotal :			140	100
13	Contingency: (approx. 43%)			60	
14	Total			$200	

mh - manhours, m - metres.

NOMENCLATURE

Symbols

C	aerodynamic coefficient
n	limit load factor
α	angle of attack
β	angle of sideslip
θ	angle of incidence
ϕ	sum of ϕ' and ϕ''
ϕ'	orientation of bomb fins
ϕ''	roll angle of the plane of incidence
$\ddot{\gamma}$	rotational acceleration in pitch plane of bomb
$\ddot{\psi}$	rotational acceleration in yaw plane of bomb

Subscripts

a	refers to aircraft body axis system
l	moment or rotation about x axis
m	moment or rotation about y axis
n	moment or rotation about z axis
t	bomb axis system
va	virtual rotational acceleration
x	axis along length of bomb
y	axis positive to the right looking upstream
z	axis positive downward
T	translation
R	rotation

9. APPENDICES

Appendix 1	:	Mass and centre of mass of filling of conventional 500 lb MK82. Filling density is 1.67 g cm^{-3}.
Appendix 2	:	Moment of inertia of filling of conventional 500 lb MK82 bomb. Filling density is 1.67 g cm^{-3}.
Appendix 3	:	Mass and centre of mass of concrete (steel-less) bomb. Concrete density is 3.2 g cm^{-3}.
Appendix 4	:	Moment of inertia of concrete (steel-less) bomb. Concrete density is 3.2 g cm^{-3}.
Appendix 5	:	Mass distribution along length of conventional 500 lb MK82 bomb with retarder tail.
Appendix 6	:	Determination of aerodynamic flight loads.
Appendix 7	:	Load, shear and bending moment diagrams for unit translational and rotational accelerations.
Appendix 8	:	Design computations.
Note 1	:	Mixed units appear within the appendices as bomb data are defined in the FPS system.
Note 2	:	The intervals 1 to 26 along the bomb length are derived from 500 lb MK82 bomb drawing NAVAIRSYSCOM 1380548 CASING, BOMB BODY.

APPENDIX 1

MASS AND CENTRE OF MASS OF FILLING OF CONVENTIONAL 500 LB MK82 BOMB

FILLING DENSITY IS 1.67 g cm^{-3}

Interval No.	Interval Length inch	Interval Radius inch	Volume $\pi R^2 L$ $inch^3$	$\bar{x}_i$	$(V)(\bar{x}_i)$
1	0.167	1.375	0.992	.0835	
2	1.625	1.375	9.652	1.063	10.26
3	0.423	1.415	2.659	2.008	5.339
4	1.024	1.761	9.976	2.727	27.21
5	1.023	2.258	16.38	3.751	61.43
6	2.048	2.694	46.68	5.286	246.7
7	2.047	3.153	63.91	7.334	468.6
8	2.048	3.367	72.95	9.381	684.4
9	2.048	3.828	94.28	11.43	1077
10	2.047	4.090	107.6	13.48	1449
11	2.048	4.312	119.6	15.52	1857
12	2.048	4.498	130.2	17.57	2288
13	2.047	4.662	139.8	19.62	2742
14	2.048	4.799	148.2	21.67	3211
15	2.047	4.902	154.5	23.71	3665
16	2.048	4.960	158.2	25.76	4077
17	13.31	4.975	1035	33.44	34610
18	2.047	4.968	158.7	41.12	6527
19	2.048	4.942	157.1	43.17	6783
20	2.047	4.891	153.8	45.22	6956
21	2.048	4.815	149.2	47.26	7050
22	2.048	4.716	143.1	49.31	7056
23	2.047	4.595	135.8	51.36	6973
24	2.048	4.453	127.6	53.41	6813
25	2.048	4.291	118.5	55.45	6569
26	1.934	4.132	103.6	57.44	5953
Total			3558		117161

Centre of Mass = 117161 ÷ 3558 = 32.93 inches (0.84 m)

Mass = 97 kg.

APPENDIX 2

MOMENT OF INERTIA OF FILLING OF CONVENTIONAL 500 LB MK82

FILLING DENSITY IS 1.67 g cm^{-3}

Interval No.	Mass in Interval (M_i) (lb)	Radius (r) (inch)	$I_{x_1x_1}$ $= \frac{M_i}{4} r^2$	Z_1 (inch)	$M_{Z_1}^{2}$	$M_1 Z_1$	(Z') *(32.93)	$(M'Z_1)^2$
1	0.060	1.375	.0281	.0835	.0004	.0050	- 32.85	64.21
2	0.580	1.375	.2737	1.063	.6544	.6156	- 31.87	588.2
3	0.160	1.414	.0798	2.008	.6431	.3202	- 30.92	152.5
4	0.600	1.761	.4641	2.727	4.451	1.632	- 30.20	545.9
5	0.983	2.257	1.252	3.751	13.83	3.686	- 29.18	836.7
6	2.801	2.693	5.080	5.286	78.26	14.81	- 27.64	2140
7	3.835	3.152	9.528	7.334	206.3	28.12	- 25.6	2513
8	4.377	3.367	12.41	9.381	385.2	41.01	- 23.55	2428
9	5.657	3.828	20.72	11.43	738.9	64.65	- 21.50	2615
10	6.454	4.090	26.99	13.48	1172	86.97	- 19.45	2441
11	7.177	4.312	30.95	15.52	1730	111.4	- 17.41	2175
12	7.811	4.498	39.51	17.57	2412	137.3	- 15.36	1843
13	8.387	4.662	45.58	19.62	3229	164.6	- 13.31	1486
14	8.892	4.799	51.20	21.67	4174	192.7	- 11.26	1127
15	9.272	4.902	55.70	23.71	5214	219.9	- 9.22	788.1
16	9.495	4.959	58.39	25.76	6302	244.6	- 7.17	488.1
17	62.10	4.975	384.2	33.44	69440	2077	0.51	16.15
18	9.523	4.968	58.76	41.12	16100	391.6	8.19	638.8
19	9.428	4.942	57.57	43.17	17570	4070	10.24	969.8
20	9.230	4.891	55.20	45.21	18870	417.3	12.29	1394
21	8.950	4.815	51.87	47.26	19990	423.0	14.33	1838
22	8.586	4.716	47.74	49.31	20880	423.4	16.38	2304
23	8.147	4.595	43.00	51.36	21490	418.4	18.43	2767
24	7.655	4.453	37.95	53.40	21830	408.8	20.48	3211
25	7.108	4.291	32.72	55.45	21860	394.2	22.52	3605
26	6.218	4.132	26.54	57.44	20520	357.2	24.51	3735
	213.5		1154		274200	7030		42710

$\rightarrow \frac{1154}{275362}$

$$Icg = 275362 - (213.48)(32.93)^2 = 43868 \text{ lb mass - inch}^2$$

$$= 12.84 \text{ kg m}^2$$

Z = dist. from nose   Z' = distance from centre of mass of filling.

* distance from machined face to centre of mass of filling.

APPENDIX 3

MASS AND CENTRE OF MASS OF CONCRETE (STEEL-LESS) BOMB

CONCRETE DENSITY IS 3.2 $g\ cm^{-3}$

Interval No.	Interval length (L) (inch)	Bomb Radius (R) (inch)	Volume (V) $\pi R^2 L$ ($inch^3$)	Centroid ($\bar{x}_i$) (inch)	(V) ($\bar{x}_i$)
1	0.167	2.337	2.865	.0835	.2393
2	1.625	2.580	33.98	1.063	36.12
3	0.423	2.850	10.79	2.008	21.67
4	1.024	3.013	29.20	2.727	79.64
5	1.023	3.233	33.59	3.751	126.0
6	2.048	3.520	71.72	5.286	379.1
7	2.047	3.851	95.37	7.333	699.4
8	2.048	4.130	109.7	9.381	1029
9	2.048	4.369	122.8	11.43	1404
10	2.047	4.580	134.9	13.48	1818
11	2.048	4.768	146.3	15.52	2271
12	2.048	4.937	156.8	17.57	2756
13	2.047	5.112	168.1	18.62	3297
14	2.048	5.213	174.8	21.67	3788
15	2.047	5.308	181.2	23.71	4297
16	2.048	5.361	184.9	25.76	4764
17	13.31	5.375	1208	33.44	40400
18	2.047	5.369	185.4	41.12	7623
19	2.048	5.344	183.7	43.17	7932
20	2.047	5.294	180.2	45.21	8149
21	2.048	5.222	175.5	47.26	8292
22	2.048	5.127	169.1	49.31	8339
23	2.047	5.011	181.5	51.36	8293
24	2.048	4.875	152.9	53.41	8166
25	2.048	4.720	143.3	53.45	7662
26	1.934	4.550	125.8	57.44	7226
Total			4363		138800

$$\bar{x} = \frac{138800}{4363} = 31.83 \text{ inch } (0.81 \text{ m})$$

Wt of Concrete Bomb (without steel)
= Volume x density
= 500 lb (227 kg)

x_i = distance from machined face on nose of bomb

APPENDIX 4

MOMENT OF INERTIA OF CONCRETE (STEEL-LESS) BOMB

CONCRETE DENSITY IS 3.2 $g\ cm^{-3}$

Interval, i No.	Mass in Interval (M_i) (lb)	Radius of Bomb Interval i(R_i) (inch)	$Ix_ix_i = \frac{Mi}{4} R_i^2$	x_i (inch)	$M_i x_i^2$
1	.3295	2.337	.4499	.0835	.002
2	3.908	2.580	6.502	1.063	4.416
3	1.241	2.85	2.520	2.008	5.005
4	3.358	3.013	7.622	2.727	24.98
5	3.863	3.233	10.09	3.750	54.32
6	8.248	3.52	25.55	5.286	230.46
7	10.97	3.851	40.66	7.334	589.9
8	12.62	4.13	53.82	9.381	1111
9	14.12	4.369	67.40	11.43	1845
10	15.51	4.58	81.35	13.48	2817
11	16.82	4.768	95.60	15.52	4054
12	18.03	4.937	109.9	17.57	5569
13	19.33	5.112	126.3	19.62	7439
14	20.11	5.213	136.6	21.67	9439
15	20.84	5.308	146.8	23.71	11720
16	21.26	5.361	152.8	25.76	14110
17	138.9	5.375	1003	33.44	155400
18	21.32	5.369	153.6	41.12	36050
19	21.13	5.344	150.9	43.17	39370
20	20.73	5.294	145.2	45.21	42370
21	20.18	5.222	137.6	47.26	45070
22	19.46	5.127	127.8	49.31	47300
23	18.57	5.011	116.6	51.36	48980
24	17.58	4.875	104.5	53.40	50150
25	16.48	4.72	91.80	53.45	47040
26	14.46	4.55	74.87	57.44	47730
Total	500 lb				

Ix_ix_i is moment of inertia of bomb interval about centre of mass of interval

$$I = \sum_{i=1}^{26} Ix_ix_i + \sum_{i=1}^{26} M_iX_i^2 = 631106 \text{ lb - inch}^2 = 184.85 \text{ kg m}^2$$

$$Icofm = I - M\bar{x}^{2} = 35.92 \text{ kg M}^2$$

APPENDIX 5

MASS DISTRIBUTION ALONG LENGTH OF CONVENTIONAL 500 LB MK82 BOMB WITH RETARDER TAIL

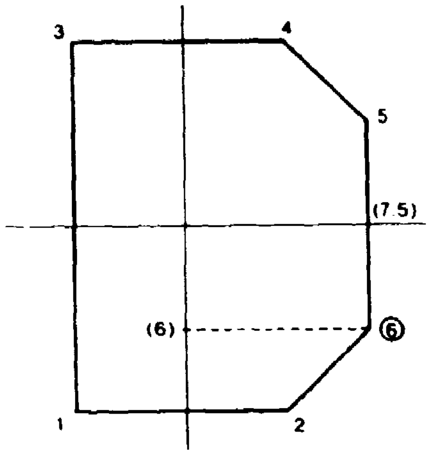
(1) Interval No.	(2) r (m) distance to cofm	(3) (lb) mass of shell	(4) (kg) mass of shell	(5) (kg) mass of filling	(6) m [(4)+(5)]x 110%	(7) mr (kg+m) i.e.(6)(2)	(8) (kg m^2) i.e.(7)(2)
1	- .9218	.5296	.2404	.0271	.2943	- .2713	.2501
2	- .8969	13.48	6.121	.264	(7.023)	- 5.698	5.111
Correction a					(-.67)		
3	- .8727	2.302	1.045	.0728	1.230	- 1.073	.9366
4	- .8547	5.441	2.470	.273	3.018	- 2.579	2.204
5	- .8285	4.868	2.210	.4482	2.924	- 2.423	2.007
6	- .7897	9.344	4.242	1.277	6.072	- 4.795	3.786
7	- .7376	8.896	4.039	1.749	6.366	- 4.696	3.464
8	- .6855	8.393	3.810	1.996	6.387	- 4.379	3.001
9	- .6335	8.075	3.666	2.580	6.871	- 4.353	2.757
10	- .5817	7.731	3.510	2.944	7.099	- 4.129	2.402
11	- .5296	7.547	3.426	3.273	7.370	- 3.903	2.067
12	- .4775	7.542	3.424	3.563	7.686	- 3.670	1.732
13	- .4261	7.532	3.420	3.825	7.970	- 3.396	1.447
14	- .3736	7.539	3.423	4.055	8.226	- 3.073	1.148
15	- .3216	7.535	3.421	4.229	8.415	- 2.706	.8703
16	- .2695	7.535	3.421	4.331	8.527	- 2.298	.6193
17	- .0716	48.99	22.24	28.32	55.62	- 3.983	.2852
18	.1461	7.533	3.420	4.343	8.540	1.248	.1823
19	.1727	7.520	3.414	4.300	8.486	1.465	.2531
20	.2247	7.480	3.396	4.210	8.366	1.880	.4224
21	.2767	7.438	3.377	4.082	8.205	2.270	.6282
22	.3287	7.375	3.348	3.916	7.991	2.626	.8633
23	.3807	7.281	3.306	3.716	7.724	2.940	1.119
24	.4327	7.168	3.254	3.491	7.420	3.211	1.389
25	.4847	7.038	3.195	3.242	7.081	3.432	1.6636
26	.5353	6.840	3.105	2.836	(6.535)	9.100	4.871
Correction b					(10.46)		
Tail	.844	-	30.2	-	30.2	25.49	45.50

Note 1: Corrections a and b are required so that tabulated and experimental values of mass, centre of mass and moment of inertia data correspond.

APPENDIX 6

DETERMINATION OF AERODYNAMIC FLIGHT LOADS

The aerodynamic loads were assessed for the conditions corresponding to point 6 on the flight envelope described below.



This diagram is an extract from the design limit load factors of Figure 10 MIL-A-8591E. The corresponding attitude of the bomb and the oncoming airstream is determined by formulae given in Figure 14 MIL-A-8591E.

MIL-A-8591E defines the attitude of the bomb by the angle of attack (α) and the angle of sideslip (β). This coordinate scheme was transformed into a system using angle of incidence (θ) and roll angle (ϕ) so that wind-tunnel data could be used; the wind-tunnel data being defined in the latter system.

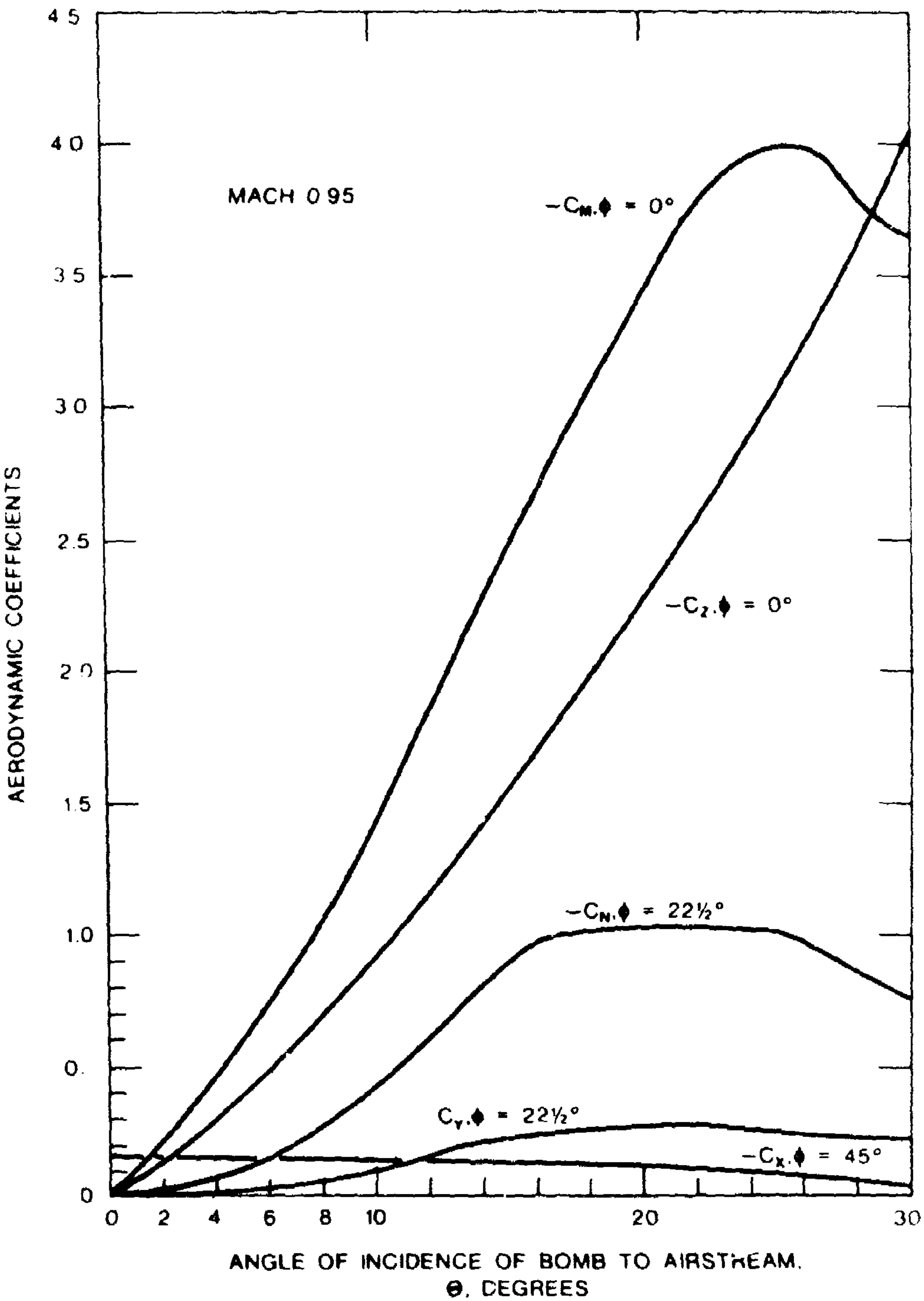
The following table gives (α,β) together, with the corresponding values (θ,ϕ''), ϕ'' is the angle through which the plane of incidence is rolled. The total roll angle between true vertical and the rolled vertical pair of fins is ϕ'' plus the orientation of the fins with respect to the aircraft, ϕ'. ϕ'' is required to transform the force and moment coefficients back onto the aircraft frame of reference; ϕ is not required for extracting these coefficients as values of ϕ are simply chosen so as to maximise the coefficients.

The incidence angle θ is similarly the sum of the incidence angle derived from (α,β) and the angle of the store with respect to the aircraft, θ'.

Each vertex of the above figure defines a continuous range of attitudes of the bomb to the airstream. The extremities of each range are tabulated. The bomb is assumed to be aligned with the aircraft i.e. $\theta' = o$ and $\phi' = o$.

TABULATION OF (θ, ϕ'') VERSUS (α, β)

	α	β	θ	ϕ''
1a	$-3°$	± 2.2	$-3.7°$	$\pm 36.26°$
1b	$+28°$	± 2.2	$28.1°$	$\pm 4.67°$
2a	$-3°$	± 2.2	$3.7°$	$\pm 36.26°$
2b	$28°$	± 2.2	$28.1°$	$\pm 4.67°$
3a	$0°$	± 2.2	$2.2°$	$\pm 90°$
3b	$20°$	± 2.2	$20.1°$	$\pm 6.4°$
4a	$0°$	± 2.2	$2.2°$	$90°$
4b	$20°$	± 2.2	$20.1°$	$6.4°$
5a	$3°$	± 10	$10.4°$	$73.2°$
5b	$-12°$	± 10	$-15.7°$	$39.9°$
6a	$-3°$	± 10	$-10.4°$	$73.2°$
6b	$25°$	± 10	$27.2°$	$22.3°$



4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.
0
MACH 0.95
$-C_M, \phi = 0°$
$-C_Z, \phi = 0°$
$-C_N, \phi = 22½°$
$C_Y, \phi = 22½°$
$-C_X, \phi = 45°$
AERODYNAMIC COEFFICIENTS
0
2
4
6
8
10
20
30
ANGLE OF INCIDENCE OF BOMB TO AIRSTREAM.
Θ, DEGREES

AERODYNAMIC LOADING: 500 LB MK 82 BOMB WITH SLICK TAIL AT PTS. 1-6 FIG. 10 MIL-A.8591E

COEFFICIENTS AIRSPEED - M = 0.95

Pt.	θ	φ"	Cxt	Cyt	Czt	Clt	Cmt	Cnt	Cxa	Cya	Cza	Cla	Cma	Cna
1a	- 3.7°	+ 36.26°	- .15	+ .04	- .28	N.R.	- .43	- .05	- .15	- .1979	.2021	N.R.	- .3171	.2946
		- 36.26°							- .15	+ .1334	.2495	N.R.	+ .3763	- .2140
1b	+ 28.1	+ 4.76°	- .05	+ .21	- 3.6	N.R.	- 3.8	- .84	- .05	+ .5023	- 3.5710	N.R.	- 3.7191	- 1.1465
		- 4.76°							- .05	- .0837	- 3.6052	N.R.	- 3.8559	+ .5279
2a & 2b	As for 1a and 1b													
3a	+ 2.2°	+ 90°	- .16	0	- .16	N.R.	- .22	- .03	- .16	+ .16	.0	N.R.	.03	- .22
		- 90°							- .16	- .16	.0	N.R.	- .03	.22
3b	20.1°	+ 6.4°	- .1	.27	- 2.27	N.R.	- 3.4	- 1.01	- .1	.5214	- 2.2258	N.R.	- 3.2663	- 1.3828
		- 6.4°							- .1	.0152	- 2.2860	N.R.	- 3.4915	- .6246
4a & 4b	As for 3a and 3b													
5a	10.4°	73.2°	- .14	.1	- .95	N.R.	- 1.5	- .44	- .14	.9384	- .1789	N.R.	- .0123	- 1.5631
		- 73.2°							- .14	- .8806	- .3703	N.R.	- .8547	1.3088
5b	- 15.7	- 39.9	- .14	+ .23	- .17	N.R.	- 2.65	- .98	- .14	- .0674	.2779	N.R.	2.6616	- .9480
		+ 39.9							- .14	- .2854	- .0171	N.R.	1.4144	2.4516
6a	- 10.4	73.2	- .14	.1	- .95	N.R.	- 1.5	- .44	- .14	- .4530	+ .8419	N.R.	1.2208	- .1622
		- 73.2							- .14	.2680	+ .9159	N.R.	1.5548	.9764
6b	27.2°	22.3	- .1	.22	- 3.4	N.R.	- 3.9	- .9	- .1	1.4937	- 3.0622	N.R.	- 3.2667	- 2.313
		- 22.3	- .1						- .1	- 1.0867	- 3.2292	N.R.	- 3.95	.647

Max. values for coefficients occur when fin. orientation φ is

Cx all φ; Cy φ = 22.5°; Cz φ = 0°; Cl N.R.; Cm φ = 0°; Cn φ = 22½°

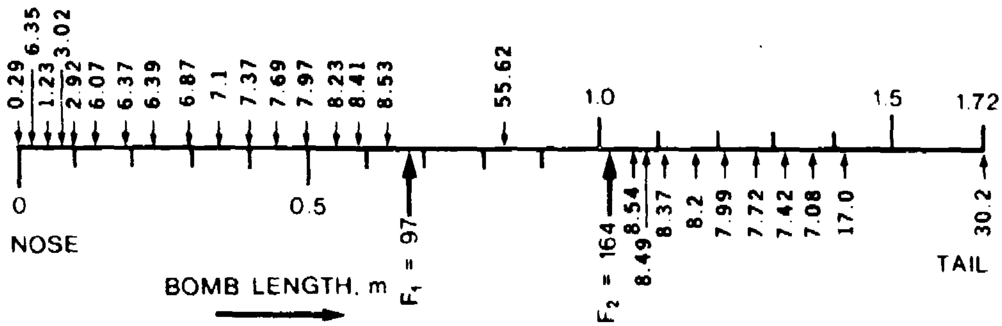
APPENDIX 7

MASS DISTRIBUTION, LOAD DISTRIBUTION, SHEAR FORCE AND BENDING MOMENT DIAGRAMS FOR UNIT TRANSLATIONAL AND UNIT ROTATIONAL ACCELERATION

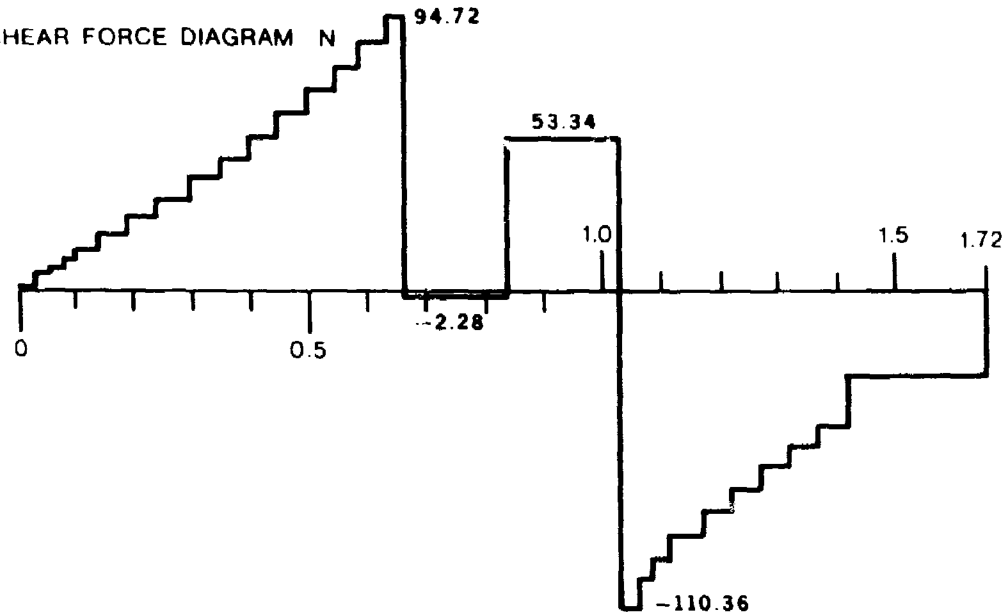
(A) EFFECTS OF UNIT TRANSLATIONAL ACCELERATION PARALLEL TO YAW OR PITCH AXIS.

i.e. n_y or n_z = 1 m sec^{-2}.

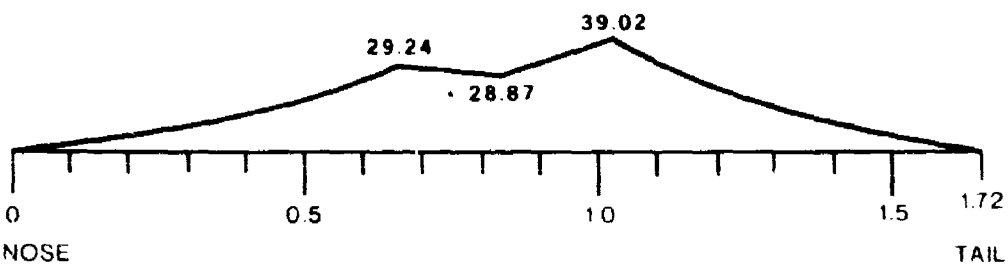
MASS DISTRIBUTION kg



SHEAR FORCE DIAGRAM N



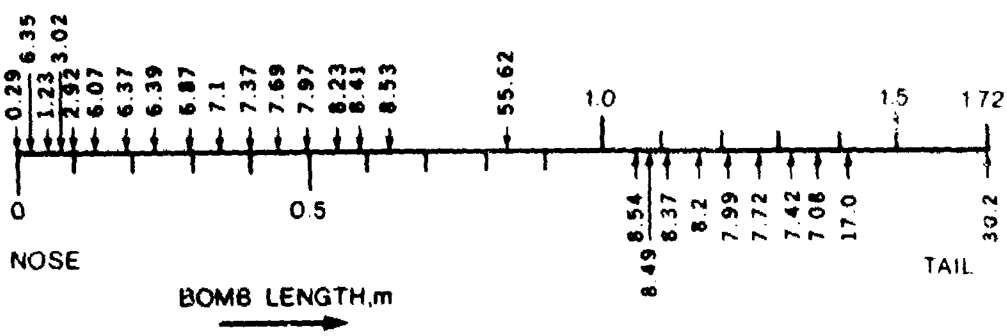
BENDING MOMENT DIAGRAM kg m



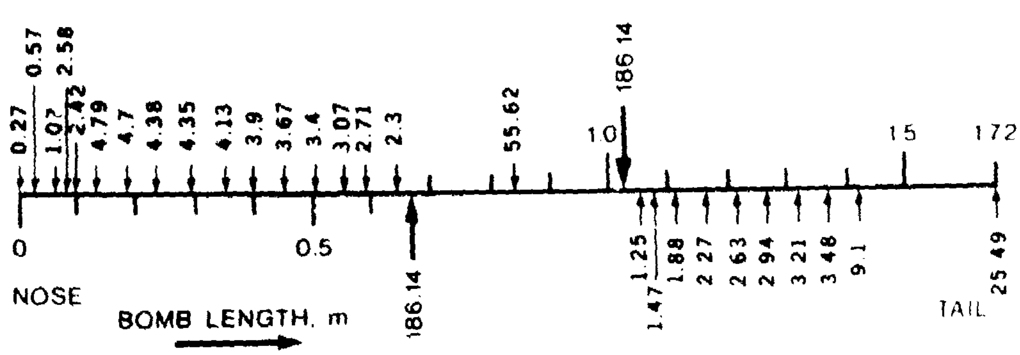
(B) EFFECTS OF UNIT ROTATIONAL ACCELERATION IN YAW OR PITCH PLANE.

i.e. $\ddot{\psi}$ or $\ddot{\phi} = 1$.

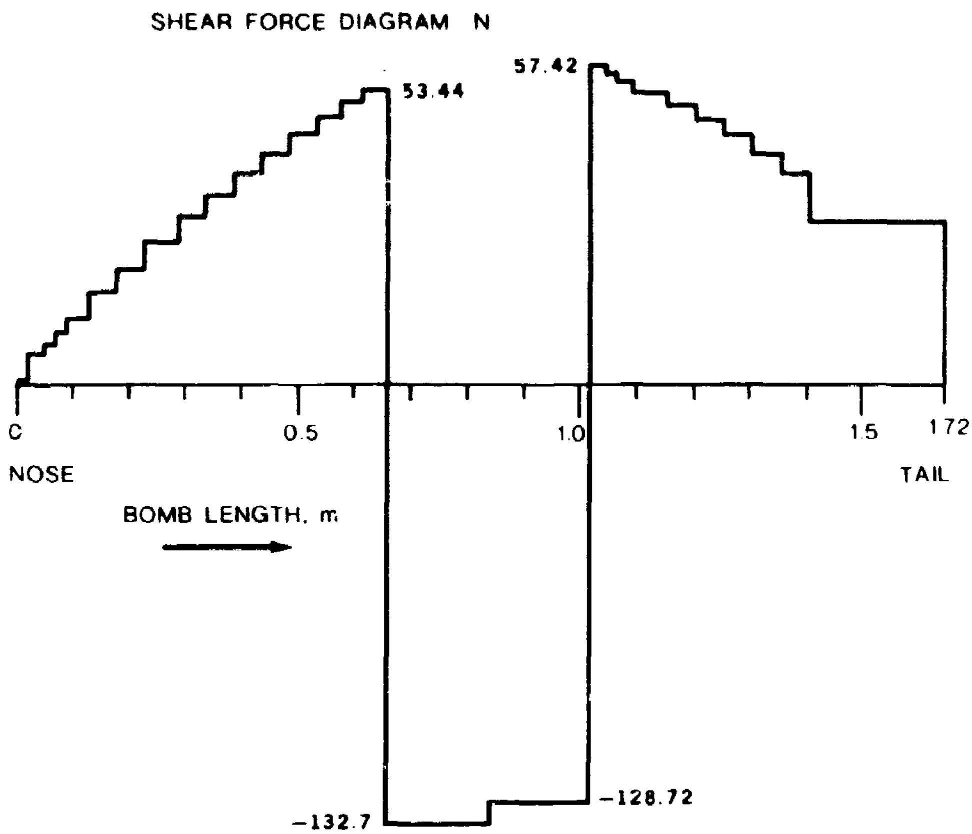
MASS DISTRIBUTION DIAGRAM kg

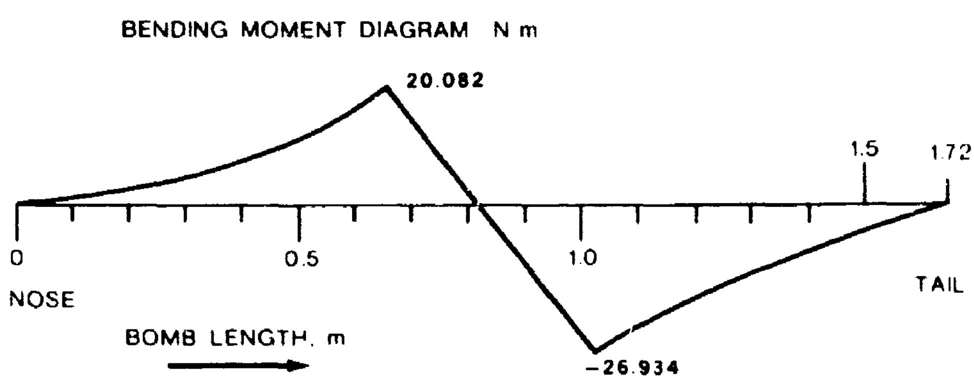


FORCE DIAGRAM N



(B) EFFECTS OF UNIT ROTATIONAL ACCELERATION **(Continued)**





APPENDIX 8

DESIGN COMPUTATIONS

For the purpose of this preliminary report an estimate of the design loads is taken for point 6 of Figure 1 of Appendix 6. This figure directly determines the inertial loadings and is the basis for assessing the aerodynamic loads. The translational inertial loads are for the 262 kg mass of a retarder tail bomb, and rotational inertia is calculated for the 67 kg m^2 moment of inertia of the same configuration.

The aerodynamic loads are from data for a slick tail bomb as aerodynamic data for the retarder tail bomb have not been located. The aerodynamic data are used realising the inconsistency and resulting error in the aerodynamic forces and moments.

TABLE OF LOAD FACTORS AND RESULTING INERTIAL LOADING

Load Factor		Inertia Force (kN)
Nx	± 1.5	± 3.85
Ny	7.5	19.27
Nz	- 6	- 15
Load Factor		**Inertial Moment (kN m)**
$\ddot{\phi}$	± 4	.27
$\ddot{\psi}$	± 2	.13
Load Factor		**Aerodynamic Force (kN)**
Cx	.14	.57
Cy	1.5	6.07
Cz	3.23	13.08
Load Factor		**Aerodynamic Moments (kN m)**
Cm	3.95	4.37
Cn	2.31	2.55

To utilise the unit rotational acceleration bending moment and shear force diagrams of Appendix 7 it is convenient to assume that the aerodynamic force distribution is equivalent to the inertial moment distribution. This gives rise to hypothetical "virtual aerodynamic rotational accelerations" in the pitch and yaw planes by dividing the aerodynamic turning moments by the moment of inertia of the bomb.

(Implicit in this analysis is the assumption that the aerodynamic force distribution is identical with the inertial force distribution. This tends to underestimate the effects of aerodynamic loads as the aerodynamic forces tend to be concentrated at the nose and tail of the bomb.)

$$\ddot{\gamma}\ va = 65.2\ \text{rad s}^{-2}$$

$$\ddot{\psi}\ va = 38.05\ \text{rad s}^{-2} .$$

TABULATION OF LOADINGS IN Y AND Z PLANES

Translation	Loading	
	y	z
Inertia	19.27	15
Aerodynamic	6.07	13.08
	25.34	28.08
Rotation	Loading	
	$\ddot{\gamma}$	$\ddot{\psi}$
Inertia	4	2
Aerodynamic	65	38
	69	40

By vectorial addition and allowing for the yield point design criterion of 1.15 times the limit load the following magnification factors are obtained. This criterion was selected as it gives a more conservative design condition than using 1.5 times the limit load for ultimate load failure criterion.

1. Magnification factor for the unit translation acceleration shear force and bending moment diagrams, $K_T = 166$, and similarly;

2. Magnification factor for the unit rotational acceleration shear force and bending moment diagrams, $K_R = 92$.

WORST CASE SHEAR FORCE AND BENDING MOMENT CONDITIONS

	Maximum Shear Force (N)	Maximum Bending Moment (Nm)
Unit Translation	110	39
Unit Rotation	133	27
Kt = 166	18260	6474
Kr = 92	12236	2484
Worst Case Conditions	30.5×10^3	8.96×10^3

2. Dimensioning of Reinforcement

(a) Reinforcement required to withstand bending

Consider reinforcement as being in the form of a thin-walled tube with diameter, d, equal to the pitch circle diameter of the reinforcing rods.

Second moment of area for a tube, $V = \frac{\pi\ t\ d^3}{8}$

where t is the wall thickness

d is the bomb diameter less 50 mm.

Set maximum stress $\sigma = 125$ MPa $= \frac{M}{J} \cdot \frac{d}{2} = \frac{4M}{\pi\ t\ d^2}$

where M is the maximum bending moment.

$$t = \frac{4M}{125\ \pi\ d^2} = 1.85 \text{ mm}$$

Area of each of 12 reinforcement rods required to

resist bending $A_1 = \frac{\pi\ d\ t}{12} = 108 \text{ mm}^2$.

(b) Reinforcement required to resist shear forces

Let maximum shear stress τ = 63 MPa cross-sectional area of each of 12 reinforcing rods required to resist shear

$$A_2 = \frac{\text{shear load}}{12} = 40 \text{ mm}^2$$

total area = $A_1 + A_2$ = 148 mm^2

$\therefore$ Individual rod diameter = 13.72 mm.

3. Check on the Compressive Stress in the Concrete

A simple check on the stress level in the concrete assuming that no reinforcement steel is used gives a compressive stress of the order of 4.5 MPa. This would also be the nominal value of the tensile stress.

DISTRIBUTION LIST

MATERIALS RESEARCH LABORATORIES

Chief Superintendent
Superintendent, Physical Chemistry Division
Head, Explosives & Ammunition Composite
Head, Explosives Devices Group
Mr. F.W. Shier
Library
Librarian, N.S.W. Branch (Through Officer-in-Charge)
Officer-in-Charge, Joint Tropical Trials and Research Establishment

DEPARTMENT OF DEFENCE

Chief Defence Scientist
Executive Controller, ADSS
Superintendent, Defence Science Administration, DSTO
Superintendent, Military Advisers Branch
Head, Laboratory Programs Branch
Army Scientific Adviser
Air Force Scientific Adviser
Naval Scientific Adviser
Chief Superintendent, A.R.L.
Director, Defence Research Centre
Senior Librarian, Defence Research Centre
Librarian, R.A.N. Research Laboratory
Officer-in-Charge, Document Exchange Centre (16 copies)
Principal Librarian, Campbell Park Library ADSATIS Annex
Central Office, Directorate of Quality Assurance - Air Force
Director, Joint Intelligence Organisation
Head, Engineering Development Establishment

DEPARTMENT OF INDUSTRY AND COMMERCE

NASA Canberra Office
Head, B.D.R.S.S. (Aust.)

OTHER FEDERAL AND STATE DEPARTMENTS AND INSTRUMENTALITIES

The Chief Librarian, Central Library, C.S.I.R.O.
Australian Atomic Energy Commission Research Establishment

DISTRIBUTION LIST

(Continued)

MISCELLANEOUS - OVERSEAS

Defence Scientific and Technical Representative, Australian High Commission, London
Assistant Director/Armour and Materials, Military Vehicles and Engineering Establishment, Eng'and
Reports Centre, Directorate of Ma rials Aviation, England
Library - Exchange Desk, National Bureau of Standards, U.S.A.
U.S. Army Standardization Group, Office of the Scientific Standardization Representative, Canberra, A.C.T.
Chief, Research and Development, Defence Scientific Information Service, Department of National Defence, Canada (2 copies)
The Director, Defence Scientific Information and Documentation Centre, India
Colonel B.C. Joshi, Military, Naval and Air Adviser, High Commission of India, Red Hill, A.C.T.
Director, Defence Research Centre, Malaysia
Exchange Section, British Library, England
Periodicals Recording Section, Science Reference Library, British Library, England
Librarian, Periodicals Recording Section, National Reference Library of Science and Invention, England
INSPEC: Acquisition Section, Institution of Electrical Engineers, England
Overseas Reports Section, Defence Research Information Centre, Ministry of Defence, England
Library, Chemical Abstracts Service, U.S.A.